



A crane in front of the convent lifts a second crane over the wall into the courtyard.

### The Tympanum.

The risk was that if the tympanum were to collapse it would destroy the roof of the chapel below, causing the loss of frescoes and works of art of inestimable value. After long reflection, it was decided to use a huge crane, 50 meters tall.

But such a crane could not pass through the narrow gate into the inner courtyard. This problem was solved using two cranes. The first crane located outside the basilica complex lifted the second

crane over the roof of the building and deposited it in the inner courtyard.

Organizing this operation involved anchoring two cantilever steel trusses on the two walls of the transept. The trusses were designed to support a 4.5-ton steel-frame structure in the shape of the tympanum, a triangle 8 meters high and 17 meters wide at the base.

The following emergency stabilization work was completed between October 10-14, 1997. The steel structures were built; two cranes arrived on the square in front of the basilica; the first crane lifted the second one into the courtyard; the two cantilever steel trusses were lifted over the roof of the transept and were anchored to the lateral walls, ready to receive the steel frame.

After some attempts hindered by heavy rain and wind, the crane succeeded in lifting the steel tympanum over the brackets. The following day the empty spaces and larger holes were filled with polyurethane foam to provisionally stabilize the masonry.

Once the urgent measures were completed and the structure relatively stable to prevent additional damage from continuing aftershock, the damaged basilica was studied and analyzed using mathematical models and the seismic retrofit and restoration was designed and executed. The second part of this article will appear in a future issue of *CRM* on disaster preparedness.

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## Mitigation— Fact or Fiction?

Most of our knowledge relating to seismic activity has come about in the last 30 years. This is a fraction of time considering earthquakes have been a fact of life for man as long as history has been recorded. It is only since the late 1960s that the theory of plate tectonics was fully understood and recognised as being the most common cause of earthquakes. The question is, "Are we using this information to the best of our ability, or are we merely information gathering?"

While the cause of seismic activity may not have been known, attempts to construct buildings able to withstand the "shaking of the ground" have been discovered dating back to the Roman Empire. Excavations at the Greek towns of Sardis and Magnesia, almost totally destroyed in an earthquake and rebuilt with the assistance of Rome, revealed unusual foundations. Structures were found with a grid of wooden beams at the foundation level and archeologists believe this may be the first attempt to construct earthquake-resistant buildings.<sup>1</sup>

Understanding what causes earthquakes makes it possible to predict with considerable accuracy where they might occur, even if we are not able to ascertain when they might happen. We also have a clear idea of the type of building that probably will and will not withstand an earthquake. With this information it should be possible to substantially reduce vulnerability of both people and buildings. If an attempt is to be

made to achieve this, it is important to understand the nature of vulnerability.

For any natural event to be viewed as a disaster it must have a human impact. This will be most pronounced in areas where the population, for a number of reasons, lives in conditions of high risk. An area prone to seismic activity will not subject all people and buildings to the same amount of risk. Within a small area, it is possible for one group to be much more vulnerable to a hazard than another.

Vulnerability has its roots in physical, social, economical and political factors. Individual or group access to, or allocation of resources within a society will be dictated to by these factors. People may be marginalized due to race or social class. It is likely they will be allocated areas of poor quality land and poorly built homes. They may be urban squatters living on the edges of towns or cities, with a low government priority to deal with hazard mitigation. With both vulnerability and potential hazard present it is only a matter of time before a disaster occurs. While economic and political factors contribute to vulnerability, the built environment is the biggest single cause of death during an earthquake.<sup>2</sup>

Building regulations exist for areas prone to seismic activity, but the long return period and the added financial cost to the work act as deterrents in carrying these out. Consequently, building regulations sometimes get side-stepped or completely ignored. Work has also been carried out on the cost of retrofitting buildings versus the repair cost if no strengthening is undertaken prior to an earthquake. This report, summarised below, demonstrates how cost cutting is a false economy and carefully thought out hazard mitigation will considerably reduce both loss to life and heritage.

In 1997, D'Ayala attempted to produce a loss estimation technique to support decision making on the upgrading of masonry buildings in historic centres in Europe.<sup>3</sup> The Alfama district of Lisbon was chosen, having suffered earthquakes in the past and been altered and extended outward and upward, using local builders and conventional low-cost construction.

Two hundred buildings were assessed, estimating possible damage for a given ground motion. This information was then used to "define expected losses for a class of building as a function of a ground motion input."<sup>4</sup> The func-

tions were verified with analysis from damage reports made after the 1755 earthquake in the area. Once the estimated loss for a given ground motion had been established, it was then possible to predict what the reduced loss might be if low cost, unobtrusive strengthening was used on masonry buildings. It was concluded that if this work were carried out the programme would reduce loss of life, rebuilding costs, and economic losses. It would also help preserve architectural heritage and reduce the cost of relief operations.

Conditions making a building unsafe are not usually visible. A survey carried out in the southern Italian town of Salvitelle highlighted how an earthquake will exploit inherent weaknesses in a building, brought about by either design or decay:

Most of the buildings had been constructed on very variable ground, often re-using inadequate old foundations and built with poor materials and with poor construction detailing. Maintenance of the fabric had been normally inadequately carried out by the owner or done 'on the cheap' with materials found at hand. Alterations in the street layout and to buildings had firstly made them rely on each other for structural support and modernisation of the houses has often reduced their structural integrity.<sup>5</sup>

This repair work may have been the result of bad planning and management from previous earthquakes. It is also known that modern materials, used for repairs and alterations, can have different behavioural characteristics, placing excessive strain on a particular area.

The condition of the subsoil will also effect the performance of a building, by amplifying the effect of the earthquake. Damage will be greater on soft ground, being more responsive to long period motion from distant earthquakes. An example of this is Mexico City. Built on a deep deposit of soil, the city sustained greater damage in the last earthquake than areas closer to the epicentre.<sup>6</sup>

A building of considerable cultural and religious significance that suffered irreparable damage in an earthquake is the Basilica of St. Francis of Assisi in Italy (see Croci, page 30). Italy sits on the meeting of three tectonic plates, making the possibility of seismic activity a potential hazard for the majority of the country.

The town of Assisi is famous the world over for being the birthplace of St. Francis and the home of the Franciscan monks. In 1228, a basil-

ica was erected to honour St. Francis and provide a home for the monks. It consisted of an upper and lower church with entrances at right angles to each other. On September 26, 1997, at 2:33 am, an earthquake of the magnitude 5.5 on the Richter scale hit Umbria, central Italy, near the city of Foligno, and was followed by at least 20 aftershocks. The second jolt, nine hours later, brought down part of the vaulted ceiling in the upper basilica damaging 14th-century frescos ascribed to Giotto.

In the early 1990s, a detailed structural analysis and restoration project for St. Francis and two other local basilicas had been carried out using "accurate direct observation and some mathematical models."<sup>7</sup> With direct observation it was evident the pattern of cracks discovered had their origins in seismic action. All three showed more or less important separation of the facade and vertical cracks along lateral walls. More serious were vertical cracks in the side walls of the upper basilica that could pose a threat to the Giotto frescos. The results of the investigation showed "...a good global behaviour under seismic action as well as dead load. But in both cases it is possible to note important local effects."<sup>8</sup>

Italy is very aware of the danger it faces and periodically work has been carried out on the basilica. It was believed the basilica, having withstood many earlier earthquakes in its history, could survive others, but this was not the case. In hindsight it should be asked if the recent damage could have been prevented, given the detailed analysis carried out. If it could have been, perhaps the situation that exists in Umbria today might have been prevented.

The damage to the basilica attracted world attention and brought money flooding in for its restoration, but it was not the worst affected area. On the outskirts of Sellano, southeast of Assisi, the locals live in "container villages"—mobile homes made of corrugated iron. The town centre, now deserted, looks as it did the day the earthquake happened. Massa Martana, south of Assisi, suffered an earthquake earlier the same year. Initially, response was good, with mobile homes provided for those who needed them. After the earthquake in Assisi, Jane Kramer, a journalist who lived nearby, visited this village and found the locals, "...bewildered and not a little angry when devastation in Massa went largely ignored, while the world poured money and

attention on Assisi."<sup>9</sup> Villages like these, in countries like Italy, are as much a part of our heritage as the basilica. Yet out of the public eye, they go unnoticed.

It is always easy to be wise after the event. Perhaps the weaknesses identified in the earlier survey on the basilica should have been reinforced, perhaps the damage would have occurred anyway. It is impossible to say. What can be said is the use of low cost, unobtrusive strengthening of masonry buildings in the area could have prevented extreme damage to historic villages and locals in Umbria might not be waiting on the basilica. Disaster preparedness does work. Yet time and time again, short-sighted government will trust to luck, hoping the disaster will occur in another party's term of office. For many people in the world today, disaster mitigation must come under the heading of fiction.

### Notes

- <sup>1</sup> N.N. Ambraseys, "The Value of Historic Records." *Nature*, Vol 232 No. 5310 August 6 1971.
- <sup>2</sup> P. Blaikie, T. Cannon, I. Davis, B. Wisner, "Earthquakes, Volcanoes and Landslides." *At Risk, Natural Hazards, People's Vulnerability and Disaster*. (London and New York: Routledge, 1994)
- <sup>3</sup> D. D'Ayala, R. Spence, C. Oliveira, A. Pomonis. "Earthquake Loss Estimation of Europe's Historic Town Centres." *Earthquake Spectra*, Vol. 13, No. 4, November 1997.
- <sup>4</sup> *ibid.*
- <sup>5</sup> R.E. Hughes, "Field survey techniques for estimating the normal performance of vernacular buildings prior to earthquakes." *Disaster Technology*, 1999, New York.
- <sup>6</sup> R. Spence, A. Coburn, "Earthquake Protection - an international task for the 1990's." *The Structural Engineer* Vol. 65A, No. 8, August 1987.
- <sup>7</sup> G. Croci, G. Carluccio, A. Viskovic, "The structural analysis and restoration projects for St. Francis, St. Claire and St. Mary of the Angels Basilicas in Assisi." *Structural Repairs and Maintenance of Historical Buildings III*. Editors: C.A. Brebbia and R.J.B. Frewer. Computational Mechanics Publications. 1992.
- <sup>8</sup> *ibid.*
- <sup>9</sup> J. Kramer, "Letters from Europe—The Shock of the Old." *The New Yorker* February 8, 1999.

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